Adaptive Optics: introduction to the feature issue

Julian Christou,[1,*] Brent L. Ellerbroek,[2] Thierry Fusco,[3] and Donald T. Miller[4]

[1]Gemini Observatory, 670 North A'ohoku Place, Hilo, Hawaii 96720, USA

[2]Thirty Meter Telescope Observatory Corporation, 1200 East California Boulevard, Pasadena, California 91125, USA

[3]Office Nationale d'Études Recherches Aerospatiale, Département d'Optique, théorique et appliquée, 29 av. de la division Leclerc, Chatillon 92322, France

[4]School of Optometry, Indiana University, 800 East Atwater Avenue, Bloomington, Indiana 47405, USA

*Corresponding author: jchristo@gemini.edu

Received 20 October 2010; accepted 20 October 2010;
posted 20 October 2010 (Doc. ID 136950); published 27 October 2010

This *Applied Optics* feature issue is a companion to the *Journal of the Optical Society of America A* feature issue on the same topic. The feature highlights the expansion of adaptive optics to different applications as well as its development to routine applications brought about because of significant advances in component technologies. © 2010 Optical Society of America

OCIS codes: 010.0010, 010.1330.

This is the second Adaptive Optics special issue to appear in *Applied Optics*. This second special issue, along with its companion special issue in the *Journal of the Optical Society of America A*, comes about after discussions held at the 2009 OSA topical meeting on Adaptive Optics held in San Jose, California. At that meeting it was realized that there had not been a special issue dedicated to this subject since the first and only one in July 1998 and much has changed in the field since then. That first special issue concentrated on adaptive optics for atmospheric correction and covered topics such as distorted wavefront statistics, horizontal path correction, control algorithms, the use of artificial guide stars, and deformable mirror technology. The intervening years have seen the adoption of adaptive optics into other disciplines, most notably vision science and ophthalmology, but also in biological imaging, beam control, and line-of-sight communication. Adaptive optics is now in routine operation at the world's largest astronomical observatories to produce diffraction-limited resolution and the use of artificial guide stars, making use of stimulated emission from the sodium layer or else by Rayleigh scattering, are now *de rigueur* significantly increasing the sky coverage. In addition, adaptive optics and its associate technologies are also being routinely used in the vision science community to measure the eye's wavefront aberrations and also for two-dimensional and three-dimensional retinal imaging for ophthalmic research. The expansion of adaptive optics to different applications as well as routine applications has been brought about because of significant advances in the component technologies. These include wavefront correctors or deformable mirrors, signal processing electronics for the control algorithms, and higher signal-to-noise wavefront detectors.

The *JOSA A* and *AO* special issues comprise a total of 43 papers, 19 of which appear herein. The majority of these papers relate to astronomical application of adaptive optics indicating that this discipline is still a driving force for technological advances. The topics covered in this issue range from modeling the turbulence that necessitates the need for adaptive optics to descriptions of full adaptive optics systems. A large number of papers discuss problems associated with measuring the aberrated wavefront, a crucial component of adaptive optics, as well as papers on deformable mirror technology and operational system calibration and performance measurement.

0003-6935/10/310AO1-02$15.00/0

The first paper illustrates the basis of any adaptive optics system, which is the turbulence that affects the incoming wavefront. To model and predict the behavior and performance of any adaptive optics system, it is important to have a good model of the system and, to do that, a realistic model of the wavefront aberrations is necessary. This paper addresses the limiting frequency regimes of two modeling schemes for atmospheric turbulence.

The next three papers address the heart of an adaptive optics system, which is the deformable mirror (DM) and how it is controlled to rectify the measured aberrations. The first of these concerns open-loop control of a microelectromechanical systems (MEMS) mirror for specific astronomical applications known as multiobject adaptive optics (MOAO), and the second involves dynamic characterization of a membrane mirror under closed-loop operation with applications for vision science and biological imaging. The third paper addresses the placement of the actuators used to control the shape of the deformable mirror and investigates optimum actuator patterns using finite element analysis.

If the DM is the heart of the adaptive optics system, then the eye is the wavefront sensor (WFS). It is the signal measured with the WFS that is used to govern the shape applied to the surface of the DM. The next nine papers concern wavefront sensing measurements and how to best generate the wavefronts or DM control signals from them. The first of these papers involves the use of two-dimensional Walsh functions for the detection and suppression of binary aberration modes; the second concerns the application of a pyramid sensor for measurement of aberrations in the human eye for both open- and closed-loop applications; the third investigates improving the performance of a curvature sensor under rapidly changing (atmospheric) turbulence; and the fourth characterizes a Shack–Hartmann sensor. A paper that compares different detectors for use with pyramid wavefront sensors follows this.

Next are three papers with the specific application of using a sodium layer laser guide star (LGS) with application for the future generation of planned Extremely Large Telescopes (30–42 m diameter apertures). With these large apertures, the mesospheric laser spot is elongated, thus affecting the accuracy of the reconstructed wavefront, and these papers investigate this problem and how to mitigate it. The final paper in this section discusses the interaction of a WFS signal and reconstructors for active mirror control.

An adaptive optics system does not deliver ideal purely diffraction-limited correction. Residual errors in the corrected wavefront are system and turbulence dependent and knowledge of these is important for scientific measurements where the morphology of the corrected beam is required. The next paper, the second of four with application to solar physics, discusses a technique to reconstruct the corrected point spread function from adaptive optics system telemetry. This is followed by a paper that simulates a system's performance running under open-loop for MOAO specifying the tolerances required for successful operation.

The next paper involves calibration for the Rayleigh LGS system being developed for the Large Binocular Telescope (LBT) adaptive optics systems that use adaptive secondary mirrors. This involves replacing standard optical bench calibration techniques with something significantly more complicated as described in the paper.

The final three papers concern adaptive optics systems themselves. All three are astronomical systems with one for nighttime astronomy and two for solar studies. The first of these presents laboratory and on-sky measurements of the recently installed and tested LBT adaptive optics system that makes use of technologies that are now coming of age. These are the use of an adaptive secondary mirror that minimizes the number of reflections between the primary mirror and the science instrument, which is important for infrared observations, and pyramid wavefront sensing that has increased sensitivity over the more traditional Shack–Hartmann systems. The following two papers concern adaptive optics systems for two different solar observatories. The first is for a small aperture, 0.27 m, telescope in Yunnan, China, and the second describes the current and planned systems for a number of telescopes operated by the Kiepenheuer Institute for Solar Physics in Germany.

Adaptive optics is now a mature discipline but is one that is still growing. The technology behind the systems continues to progress, which will determine future applications in this field. To quote the editors of the first special issue:

"…Continuing research in these and related areas will doubtless lead to further scientific and technological advances."

We still believe this to be true 12 years later, and we look forward to the technology, applications, and science that will be made possible in the next decade.